Interference Estimate around Canberra DSN Station at 2.04 GHz during Huygens Release Phase from Cassini[1,2]

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Abstract— During the descent phase of the Huygens Probe released from the Cassini spacecraft and inserted at Titan, the Deep Space Network (DSN) Canberra Deep Space Station (DSS) 43 (with its 70-m antenna) is being considered as a backup station to directly receive the Huygens Probe data being transmitted at 2.04 GHz. This study provides an assessment on the interference level from the major nearby transmitters operating in this frequency band. The minimum trans-horizon attenuations are calculated using terrain topographic data and the Trans-Horizon Interference Propagation Loss (THIPL) Computing Program recently developed based on ITU-R P.452, and the calculations take into account all propagation modes under a 0.1% of time exceeded. We find that there are five terrestrial transmitters within 100 km of DSS 43. Transmitter 1 is the closest to DSS 43, and needs to be coordinated to avoid interference. The rest of the four transmitters will not interfere with DSS 43. The interference levels from these transmitters are all below the DSN protection criteria of 99.9% of time.

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1. INTRODUCTION

During the coming entry, descent, and landing (EDL) phase of the Huygens Probe when the Probe will be released from the Cassini spacecraft and inserted at Titan, Saturn's moon, near the end of 2004 [1, 2], the Deep Space Network (DSN) Canberra Deep Space Station (DSS) 43 (with its 70-m antenna) is being considered as a backup station to the Huygens Probe as shown in Figure 1. The Probe may transfer data at 2.04 GHz directly to Earth to secure the unique data acquisition in case of unexpected Doppler effects relative to the Cassini spacecraft. The Earth station DSS-43 has much more flexibility in frequency tuning for receiving the signals from the Probe. After propagating along a path of roughly $1.4x10^9$ km, the signals from the Huygens Probe become very weak. However, because of DSS-43 receiver's high sensitivity [3], it can catch such signals from the deep space as long as interference signals from surrounding Earth environment is below the DSS-43's threshold. Thus, this study provides an assessment on the interference level from the major nearby transmitters operating in this frequency band. Similar interference studies were performed before for a DSN Earth station at Goldstone, California at S band [4, 5].

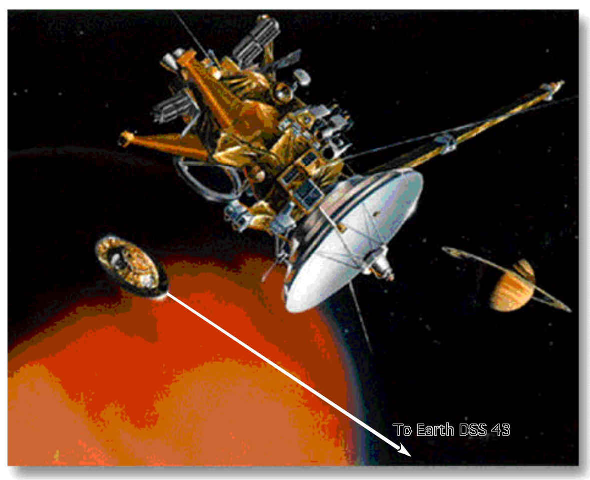

Figure 1 - During the Huygens Probe descent into Titan from Cassini spacecraft, the probe may transfer signal directly to Earth DSS 43 station located at Canberra, Australia.

2. ANALYSIS

2.1 Terrain Elevation Data

As shown in Figure 2, there are at least 13 pairs of terrestrial transmitter systems distributed around the areas of DSS-43.

[1] 0-7803-8870-4/05/$20.00© 2005 IEEE
[2] IEEEAC paper #1138, Version 2, Updated November 20, 2004

Each pair consists of a transmitter and receiver in both ends of terrestrial links. However, there are only five terrestrial transmitters within 100 km of DSS 43. Their coordinates and positions of the five transmitters with respect to (wrt) DSS 43 are shown in Table 1 (DSS 43 is row 0 in the table) [6]. Those unmarked stations are either receivers or transmitters beyond 100 km ranges (with relative small changes in their power and antenna gain).

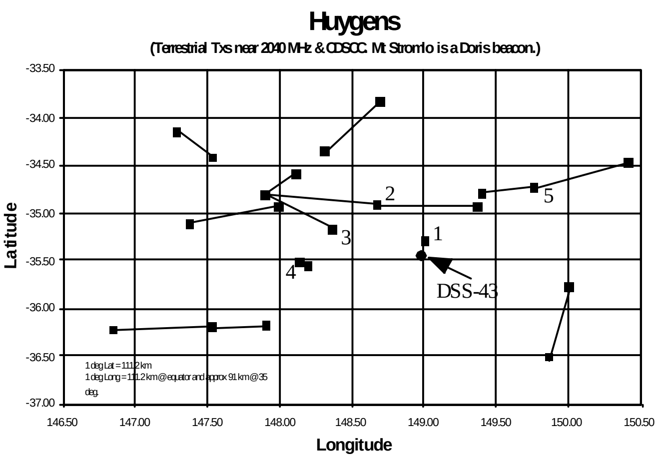

Figure 2 - Distribution of transmitter pairs around DSS-43 near Canberra, Australia (Courtesy of Ian Mac Andrews of CSIRO).

There are several azimuth angles which are needed to be defined first. In the sixth column of Table 1 is transmitter's azimuth angle with respect to DSS 43 (noting that azimuth angle starts from the geographic north). The second angle is transmitter antenna's azimuth angle (that is its link orientation) with respect to the north (seventh column in Table 1). As shown in Figure 2, each transmitter points its antenna to its pair of receiver for transmission link. In this study we do not consider any effects from those terrestrial receiver stations, because they do not transfer signals at studied frequency, even though they may have closer distance to DSS 43 than their transmitter pairs. From the two angles, we can calculate the third angle: transmitter boresight azimuth angle with respect to DSS-43 using the following relation:

$$\text{Tx boresight Az angle} = |\text{Tx Az angle} - 180° - \text{Tx Antenna Az angle}| \qquad (1)$$

If the resultant angle is greater than 180°, using its complementary angle of 360° instead, as shown in the last column in Table 1. We will later use this angle to determine the interference levels from each transmitter.

Figure 3 shows the terrain elevation in an area of 200 km distance in each direction relative to the DSS-43 and the five transmitter locations that may impact DSS 43. The terrain topographic data we used in this study have 900-m horizontal spatial resolution. The terrain data are obtained from Institute of Telecommunication Sciences from their global terrain database.

From the terrain map, we can see that there are major mountains oriented from south-western to north-eastern. Northwest area in the map is a plateau, while far-east is the ocean. The DSS-43 station has a 70-m dish antenna and is located in a small valley [3]. Its antenna base has an elevation of 640m. In its south and southwestern sides there are large mountains over 1500m above the sea level. Its east side faces a small hill with a height of 810m, while the north side is an open valley. Canberra City is northeast about 20km away.

Five transmitters are distributed within the mountain area around DSS-43. Due to the mountain shielding, there are probably no direct line of sight from transmitters to DSS-43, except transmitter 1 which is too close to be blocked.

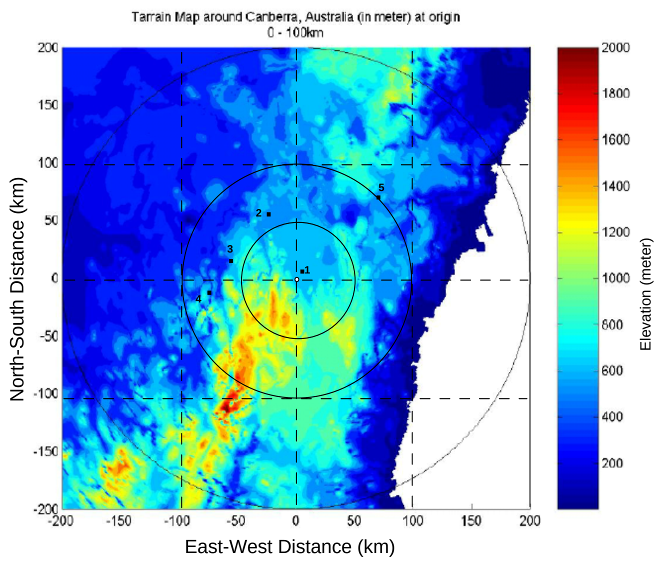

Figure 3 - Terrain elevation map around Canberra DSS 43. The locations of five nearest terrestrial transmitters are also shown with numbers.

2.2 Trans-Horizon Propagation Modes

In this study, interference propagation modes we investigated include the line of sight mode and several anomalous trans-horizon propagation modes.

The loss for a line of sight path is:

$$L = 92.45 + 20\log f + 20\log d + L_A \quad in \quad dB \qquad (2)$$

where frequency, f, is in GHz, distance, d, is in km, and L_A is the gaseous absorption loss.

Due to the terrain shielding, almost all transmitters do not have direct line of sight view with DSS-43. The interference signals can only propagate through a trans-horizon path along the great circle into the victim station [7]. Interference through these modes at a very small percent of time can be significant. Anomalous modes propagation mechanisms depend on climate, radio frequency, time percentage of interest, distance, and path topography. At any one time a single mechanism (or more than one) may be present. Basically there are three types of anomalous modes we are interested in in this study [7].

Terrain diffraction: Radio signals can be diffracted by hilltops or rounded obstacles and propagate beyond the line of sight. Diffraction effects generally dominate a surrounding area (with a radius < 200 km) and define the long-term signal levels. Diffraction losses increase with increasing signal frequency and obstacle sharpness, but have a weak dependence on the percentage of time. Diffraction loss over a hill is calculated using a multi knife-edge model in this study.

Tropospheric scatter: Radio signals can be scattered by the tropospheric particles or turbulence to propagate forward into a large distance beyond the line of sight. This mechanism defines the "background" interference level for longer paths (e.g., more than 100–150 km) where the diffraction field becomes very weak. For an earth station as sensitive as DSS-43, interference via troposcatter can be significant.

Ducting (surface and elevated): Due to the surface heating and radiative cooling, inversion temperature layers often are generated on the ocean or flat coastal surface without large mountains. Radio signals can be trapped within this reflection layer at heights up to a few hundred meters and propagates over a long distance (>500 km over the sea). Such signals can even exceed the equivalent "free space" level occasionally.

Generally, for short transmission paths extending only slightly beyond the horizon, terrain diffraction is the dominant mechanism in most cases. Conversely, for longer paths (more than 100 km), scattering and ducting mechanisms need to be taken into account if there is no large mountain in between.

2.3 Software for Loss Calculation

These propagation losses are calculated using a sophisticated computer software called Trans-Horizon Interference Propagation Loss (THIPL) which was recently developed at JPL based on ITU (International Telecommunication Union)-R P.452 recommendation [7] for calculating trans-horizon interference attenuation. The calculation takes into account of all propagation modes under a 0.1% of time exceeded. At a lower percent of time, lower loss is expected for modes because of more favorable propagation conditions.

The software takes terrain path profile analysis first. For the sake of simplification, we calculate the propagation loss along each radial terrain profile starting from the centered DSS-43. Thus the terrain data are organized by 360 radial profiles by every 1° azimuth separation. The software identifies whether a path from the transmitter's antenna has a line of sight or not relative to the DSS-43 receiving antenna. Radio waves are bent when they propagate through atmospheric gases that decrease in density with altitude. The waves can therefore reach locations beyond the line of sight. The severity of the bending is determined by the gradient of the refractive index, ΔN, near the earth's surface. The software has taken into account of the ray bending effect.

We have used the following parameters for interference propagation loss calculation:

F (signal frequency) = 2.04 (GHz)
T (time percentage) = 0.1 (%)
H (transmitter antenna height) = 10 (m)
h (receiver antenna height) = 37 (m)
G (transmitter antenna gain) = 36 (dBi)
g (receiver antenna gain) = 0 (dBi)
N_0 (surface refractivity) = 330
ΔN (vertical refractivity gradient) = 45
β (time percentage for which ΔN >100) = 1.35

2.4. Propagation Loss Maps and Profiles

To make the propagation loss map, we have run the THIPL software for each terrain profile between the transmitter and the DSS-43 to calculate losses for all three modes. The loss for each mode is calculated every 1° in azimuth along a radial profile from its center (0 km) to a maximum distance of 300 km by a step of 0.1 km. The minimum propagation losses among three types of losses are finally chosen for making a 3-D loss map as shown in Figure 4. To make the map, the linear interpolation has been used between the adjacent data points. Thus, near the center of the map, there is higher spatial resolution because of denser radial lines, while outside the map has lower resolution because of less line coverage.

The map has a 400x400km dimension with DSS 43 at its center. The color bar has a loss range from 100 to 250 dB with 5 dB in step. Red color shows larger losses mainly caused by the terrain shielding and very well correlated with downstream side shadows of terrain, while blue color shows the areas with less losses correlated with flat regions. We can see that in the southwest direction, there are larger propagation losses, while in the north and east directions there are less propagation losses. Above the ocean and plateau regions, loss map shows relative small changes with distances. There are some ray-type structures radiated from the center of the map. These structures may be caused due to long shadows of large mountains or open valleys.

For the five nearest transmitters, the terrain elevation and corresponding minimum propagation loss profiles are plotted along the various azimuth angles in Figures 5.1 through 5.5, respectively. Left scale (blue line) shows terrain elevation, while right scale (red line) shows minimum propagation loss.

The vertical line in each figure gives the location of the transmitter. These figures clearly show how the signal attenuations change with a terrain profile, indicating that terrain diffraction plays a major role. Large losses always appear in the downstream side shadows of terrains. In the shadow sides of the mountaintops, there are always larger attenuations than their forward sides. Each hill can cause an increase of loss at least by 30 – 50 dB. Generally, propagation losses increase from 100 dB to above 200 dB over a 300 km path.

Based on the propagation attenuation map showed in Figure 4, the loss profiles shown in Figure 5, and the transmitter parameters provided from Ian MacAndrews [6], we can calculate the maximum interference levels from the four nearest transmitters (Parameters for Transmitter 1 are not available). Antenna parameters and calculated results are shown in Table 2.

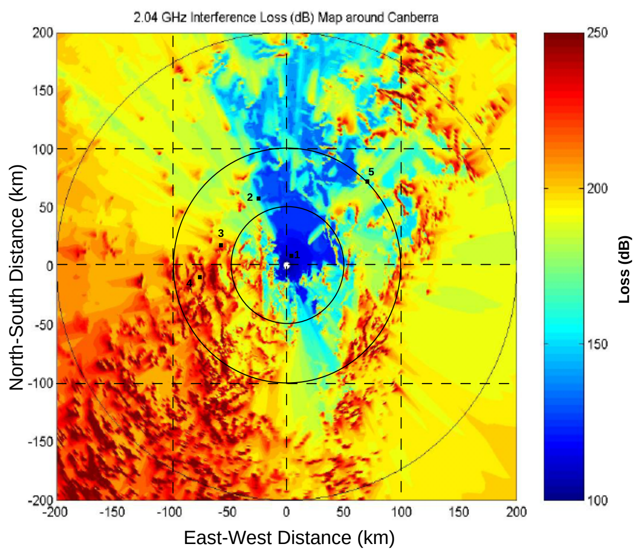

Figure 4 - Minimum propagation loss map as a function of distance from Canberra DSS 43. The color codes show the loss levels.

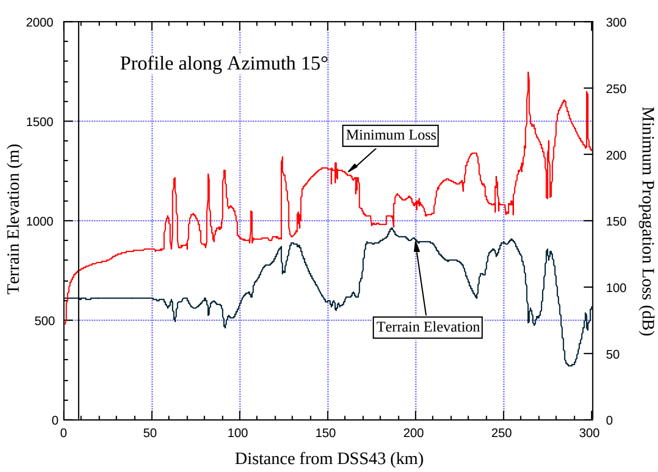

Figure 5.1 – Terrain elevation and propagation loss profiles along the azimuth 15° relative to DSS 43. Transmitter 1 is located 9.75 km away, as shown by the vertical line. The loss is 113.4 dB.

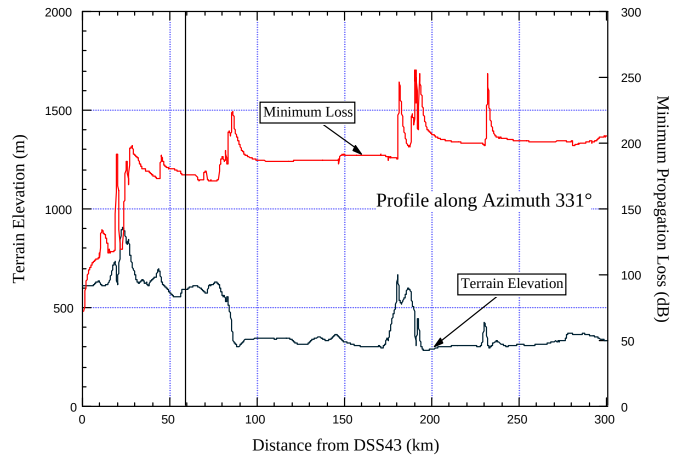

Figure 5.2 – Terrain elevation and propagation loss profiles along the azimuth 331° relative to DSS 43. Transmitter 2 is located 59.1 km away, as shown by the vertical line. The loss is 176.0 dB.

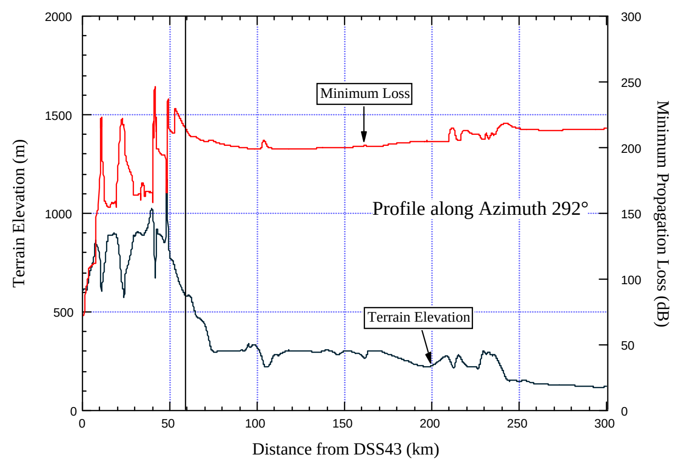

Figure 5.3 – Terrain elevation and propagation loss profiles along the azimuth 292° relative to DSS 43. Transmitter 3 is located 59.76 km away, as shown by the vertical line. The loss is 212.6 dB.

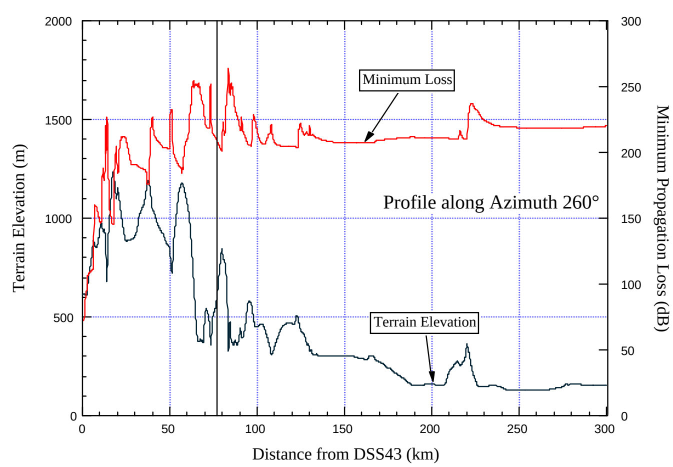

Figure 5.4 – Terrain elevation and propagation loss profiles along the azimuth 260° relative to DSS 43. Transmitter 4 is

located 76.97 km away, as shown by the vertical line. The loss is 209.3 dB.

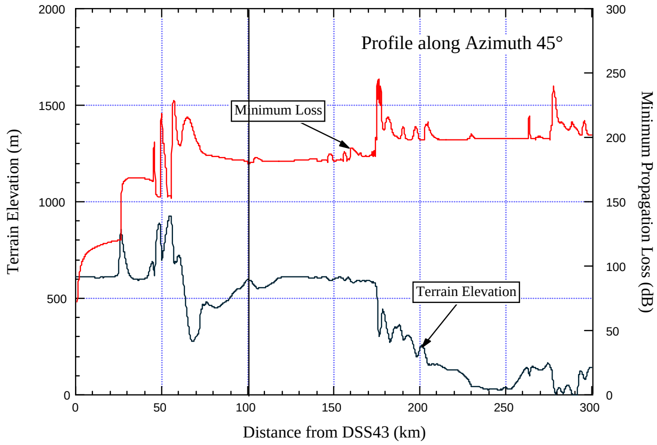

Figure 5.5 – Terrain elevation and propagation loss profiles along the azimuth 45° relative to DSS 43. Transmitter 5 is located 100.75 km away, as shown by the vertical line. The loss is 180.7 dB.

There are two ways to estimate the interference intensity at DDS-43. The first one is to calculate the exact antenna gain ($G_t(\varphi)$) in the direction of DSS-43 for each transmitter using its antenna pattern, then using following equation to find out received interference power density, P_r (in dB) for DSS-43:

$$P_r = P_t + G_t + G_r - L \qquad (3)$$

where P_t is transmitted power density which has been calculated (listed in column 7 of Table 2) using transmitted power (column 2) and bandwidth (column 3) for each transmitter, G_t and G_r are respectively antenna gains in the direction from transmitter to DSS-43, while L is the minimum propagation loss we calculated in this study.

The second one is to calculated 0-dB off-boresight angle for each transmitter antenna under assuming that both G_t and G_r have 0 dB gains in the direction toward each other. Then the received interference power density, P_r (in dB) is calculated using: $P_r = P_t - L$. After comparing the calculated 0-dB off-boresight angle with transmitter boresight azimuth angle with respect to DSS-43, the applicability of P_r will be determined. If the latter is larger than the former, this means that actual transmitter's antenna gain in the DSS-43 direction is less than 0 dB. Thus the receiving power (P_r) is over-estimated.

We have employed the second approach to estimate the interference power in this study because of its simplicity. We have calculated each transmitter antenna off-boresight angle for the 0-dBi based on antenna models from ITU-R F.699 [8] for a case where the ratio between the antenna diameter and the wavelength is less than 100. The following antenna pattern is used to find 0-dBi off-boresight angle (φ_0) for various antenna size D:

$$G(\varphi) = 52 - 10\log(\frac{D}{\lambda}) - 25\log\varphi \;\; for \;\; 100\frac{\lambda}{D} \le \varphi < 48^\circ \qquad (4)$$

The calculated 0-dBi off-boresight angles are listed in the sixth column of Table 2. In this study, we have assumed that transmitter antenna gain in the direction of DSS 43 is 0 dB (Column 8 in Table 2). Under these antenna gains and propagation loss values (Column 9) we have calculated interference power densities received by DSS-43 using the relation $P_r = P_t - L$. These interference intensity values (in dBW/Hz) are listed in the last column of Table 2.

3. Results

Based on the boresight azimuth angles of the transmitters respective to the DSS 43 listed in the eighth column of Table 1, we have determined that these angles are greater than 0 dBi off-boresight angles for Transmitters 2 through 5. Thus, the assumption of 0 dBi transmitter antenna gain is conservative. Because the actual transmitter antenna gain is overestimated, our estimates on interference levels are also conservative. Except for Transmitter 1, the interferences from the four other transmitters are all below the DSN interference protection threshold of –222 dBW/Hz [9] (The signal intensity received from Huygens Probe will be above this level after overcoming a huge space loss). We note that roughly there is a distance of 1.4x10^9 km between Saturn and Earth. The pure space loss of signals from Huygens to Earth is about 190 dB at S band.

Transmitting power for Transmitter 1 is unknown. Because its propagation loss is significant less than those from other 4 transmitters, this transmitter definitely needs to be coordinated.

4. Conclusion

Transmitter 1 is the closest to DSS 43, and its parameters are not all known. Hence, this transmitter needs to be coordinated to avoid interference. The rest of the transmitters will not interfere with DSS 43 at 2.04 GHz. The interference levels from these transmitters are all below the DSN protection criteria of 99.9% of time. Thus, these transmitters will not cause any problem during Huygens Probe telemetries from Saturn to DSS-43 Earth station. Calculations using a higher resolution terrain map may result in larger calculated propagation losses between the transmitters and DSS 43. Therefore, using higher resolution terrain data might generate less interference than obtained in this study. Thus this study provides a conservative estimate on potential interference problem from adjacent terrestrial transmitters with DSS-43.

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Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Table 1. Nearest Five Terrestrial Transmitter (Tx) Coordinates*

Tx Number	Tx Location	Tx Longitude (deg)	Tx Latitude (deg)	Distance to DSS 43 (km)	Tx Az Angle wrt DSS 43(deg)	Tx Antenna Az Angle (deg) wrt N	Tx boresight Az Angle wrt DSS 43 (deg)
0	DSS43	148.9813	-35.4025				
1	Mt. Stromlo	149.0087	-35.3177	9.75	14.77		
2	Mt. Carroll	148.6711	-34.9352	59.10	331.42	91° & 280°	60.4° & 128.6°
3	Via Tumut	148.3728	-35.1964	59.76	292.36	314°	158.4°
4	Batlow	148.1438	-35.5216	76.97	259.85	120°	40.2°
5	Mt. Gray	149.7622	-34.7596	100.75	45.05	264°	39.0°

* All information from the email of Ian MacAndrews

Table 2. Transmitter (Tx) Parameters, Propagation loss and Interference Intensity

Tx No.	Tx Power (W)	Tx Band-width (MHz)	Tx Boresight Gain (dBi)	Tx antenna size (m)	Tx 0-dBi off-Boresight Angle*	Transmitted Power Density (Pt) (dBW/Hz)	DSS 34 Antenna Gain (dBi)**	Propa-gation Loss (dB)	Interference Intensity (dBW/Hz) for DSS 43
1	?	0.1						113.4	
2	12.0	28	31.9	2.4	39.6°	-63.68	0	176.0	-239.68
3	1.6	25	34.8	3.7	33.3°	-71.94	0	212.6	-284.54
4	1.0	25	33.8	3.0	36.3°	-73.98	0	209.3	-283.28
5	5.0	11	35.8	4.0	32.3°	-63.42	0	180.7	-244.12

* Assumed 0 dBi transmitter antenna gain in the direction of DSS 43

** Assumed DSS 43 antenna gain in the direction of the interference source

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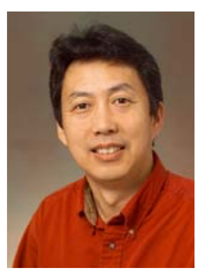

BIOGRAPHY

Christian Ho is a senior telecommunications system engineer at the Jet Propulsion Laboratory. He is an expert in radio wave propagation in various environments (ionized and non-ionized media). He received his PhD in Space Physics from UCLA and joined JPL in 1993. He has over 100 publications in a wide variety of fields, including radio wave propagation in the Earth's magnetosphere, ionosphere, plasmasphere, solar corona, atmospheric reentry at Venus and Mars; interference propagation in terrestrial environments; Deep Space Network interference protection; and various ITU studies. He is an expert in ITU (International Telecommunication Union) regulations and spectrum coordination, and he has made many contributions in drafting recommendations and issues for ITU.R Working Group.

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